MERCED RIVER WING DAM
GRAVEL MONITORING
2000 - 2002

FINAL REPORT

March 2003

Conducted by:

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INTRODUCTION

Construction of dams on the Merced River has impeded the movement of coarse gravels through the river system. Consequently, areas downstream of dams lack recruitment of salmon spawning gravels from areas upstream of those sites. Chinook salmon require these coarse gravels for successful spawning. Addition of appropriately-sized gravel in riffles immediately below Crocker-Huffman Dam has shown an immediate response in salmon spawning activity. One strategy for increasing natural production of salmon on the Merced River is to replenish spawning gravel at key locations. As the rivers are continuously carrying this coarse sediment downstream, its replenishment is an ongoing need.

Current studies funded by CALFED are developing models to simulate sediment input needs and transport rates appropriate for the flows of the Merced River. This project is intended to provide data to supplement the modeling effort and to evaluate the use of wing dams as gravel introduction sites.

On the Merced River in the area around the town of Snelling, there are several riparian diversions that are operated by the construction of wing dams in the spring (Figure 1). These wing dams are peninsulas consisting of streambed substrate that extend into the river to create partial hydraulic controls that raise the water surface elevation and enable gravity flow of water into the riparian diversion ditches. The dams typically wash out with winter and spring runoff flows, carrying the construction material downstream. The diversion operators, or riparian diverters, re-build the wing dams with miscellaneous fill or material from previous construction that has washed downstream into the river channel. They normally use any fill material available, including fine sediment which can be deposited downstream after mobilization and consequently impact spawning areas.

If provided with clean spawning-sized gravel, some of the riparian diverters will use it for wing dam construction (example shown in Figure 2). This project monitored movement of spawning-sized gravel from these wing dam sites under flow conditions experienced during the study period. To monitor gravel movement, two techniques were used: painted tracer rocks and radio-tagged telemetry rocks. This information may be useful in assessing whether these diversions are suitable locations for gravel introductions.

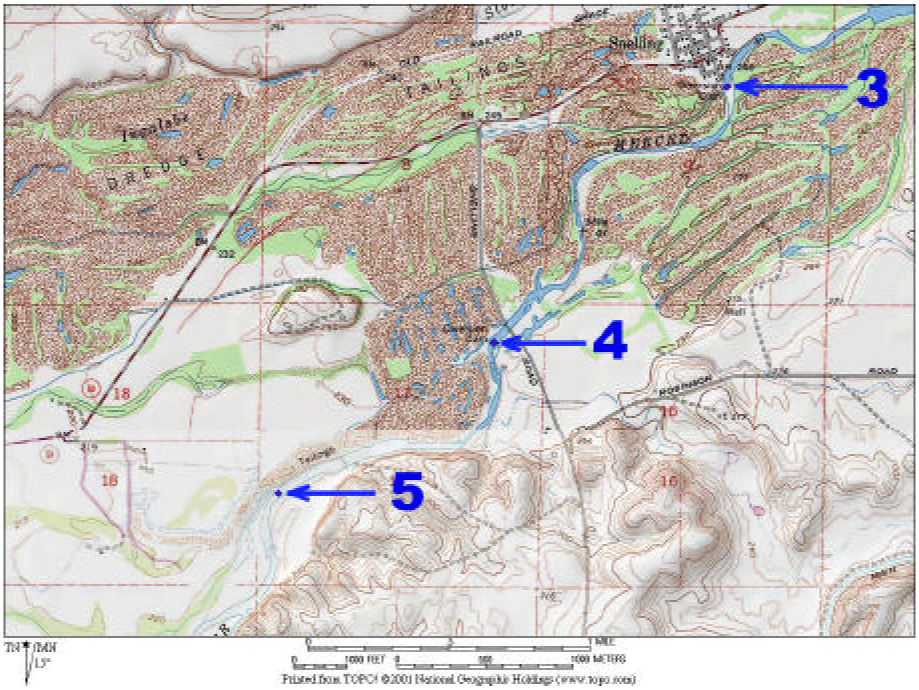

Figure 1. The Merced River near the town of Snelling showing the locations of wing dams used in this study. Wing dam numbers 3, 4, and 5 are study sites referred to in this report.

Figure 2. Supplementation of clean salmon spawning gravel at a wing dam in the Merced River (location is wing dam no. 4 shown in Figure 1). New gravel is imported and added on top of the older material on the existing wing dam. Prior to the irrigation season, clean gravel is distributed out into the river to create a partial hydraulic control raising the water surface and providing gravity flow of water into the diversion (on right). Photo taken on February 20, 2003.

METHODS

Overview

The downstream movement and distribution of spawning-sized gravels in three wing dams (Figure 1) were monitored by placing tracer gravel in the wing dams prior to high-flow periods. Tracer gravel was composed of painted rocks and, as a pilot effort, twenty rocks tagged with radio transmitters. Tracer rocks were of a comparable size used by Chinook salmon for spawning. A known number of rocks were coated with a durable paint to allow for later identification. Spawning-sized rocks were also tagged with radio transmitters by drilling holes and cementing the radio tags in place. Each radio tag had a unique frequency to allow for later identification of individual rocks. The transmission pulse rate was set to allow the tag to transmit for at least two years. Both the painted rocks and the radio-tagged rocks were used to observe patterns of bed movement, document wing dam substrate mobilization, and estimate distribution to downstream areas. The tracer gravel was intended to be monitored after significant flow events, generally greater than or equal to 3,000 cfs, for a period of 2 years (the expected duration of the tag). Locations of painted and radio-tagged rocks were mapped with a Global Positioning System (GPS) during the surveys.

Tracer Gravel Selection

Gravel used for the tracer rocks was chosen to match that installed as spawning gravel supplementation by the California Department of Fish and Game (CDFG) at diversion wing dams. The tracer gravel was obtained from Merced Irrigation District's (MID) property along the Merced River, approximately two miles above Snelling. This site contained a large amount of dredger tailings. A bulk amount of tailings was transferred to the MID Franklin Yard where it was processed. Gravel for each of the three diversion sites was sorted by sieve, using a six-sieve series (Table 1).

Table 1. Gravel sizes (sieve openings) used in the Merced River wing dam monitoring.

½ inch – 1 inch	12.7 mm – 25.4 mm
1 inch – 2 inch	25.4 mm – 50.8 mm
2 inch – 3 inch	50.8 mm – 76.2 mm
3 inch – 4 inch	76.2 mm – 101.6 mm
4 inch – 5 inch	101. 6 mm – 127.0 mm
5 inch – 6 inch	127.0 mm – 152.4 mm

Each size class was enumerated and weighed yielding the percent contribution of each class. In addition, up to thirty, three-dimensional measurements were obtained for each size class using calipers (X = longest plane, Y = second longest plane, Z = shortest plane; length, width, and depth, respectively). The average diameter of each individual rock was determined with the mean diameter of each size class. Information was compiled and the geometric mean (d_g) calculated as described in Lotspeich and Everest (1981) for each of the wing dam tracer gravel groups:

$$d_g = [d_1^{w1} \text{ x } d_2^{w2} \ldots\ldots \text{ x } d_n^{wn}]$$

where

d_g = geometric mean particle size.
d = midpoint diameter of particles retained by a given sieve.
w = decimal fraction by weight of particles retained by a given sieve.

To ensure that the rocks selected for the study matched those installed in the river by CDFG, and to ensure that they were of suitable size for spawning, the gravel was sorted to reflect parameters described by Puckett (1969) (Table 2), then compared to the gravel installed by CDFG (excluding rocks over eight inches in diameter and less than one-half inch in diameter.)

Table 2. Substrate criteria for identifying potential chinook salmon spawning habitat (from Puckett 1969).

Gravel Size (inches)	Percent by Volume
6 – 12	30 or less
3 – 6	10 or more
1 – 3	50 or less
1/2 – 1	*20 or less
5/32 – ½	*20 or less
0.015 – 5/32	*20 or less

* The three smallest sizes in combination should not exceed 50 percent.

To compare the selected tracer gravel to that installed by CDFG, gravel at each of the three study sites was sampled using a modified McNeil-Ahnell hollow-core sampling technique. In place of a McNeil sampler, a modified five-gallon bucket was used. The bottom of the five-gallon bucket was removed and the bottom edge serrated. Eight inches from the bottom of the bucket, a line was drawn around the outside. Depending on the homogeneity of the gravel, at least three random samples of CDFG-installed gravel were taken. The samples were obtained using the five gallon bucket by twisting with downward pressure and removing gravel from inside the bucket while clearing larger rocks away from the outside during the process. The bucket was depressed into the gravel down to the eight-inch line and contents excavated to the base of the bucket (Figure 3).

Figure 3. Extraction of gravels from the wing dams.

The contents of the three samples for each study site were combined and sorted using the six-sieve series technique previously described. As with the tracer gravel, each size class was weighed and the geometric mean calculated using methods described in Lotspeich and Everest (1981). In addition, up to thirty rocks of each size class were measured to three dimensions along the X, Y, and Z planes using calipers. The individual mean diameter was calculated along with the mean diameter of each size class.

Tracer Gravel Preparation

Rocks to be painted were washed in a 32-gallon plastic can with a bottom drain using the following procedure:

1. Adding 5 - 10 gallons of rocks.
2. Adding 5 gallons of water and swirling vigorously. Draining water.
3. Repeating step 2 twice.
4. Transferring rocks to a second 32-gallon plastic can with a bottom drain leaving any fines in the first can.
5. Adding 5 gallons of water and swirling vigorously. Draining water.
6. Closing drain and washing in Muriatic acid solution (1:5 ratio).
7. Draining and neutralizing.
8. Repeating steps 2 and 3.
9. Spreading rocks out to dry.

Clean rocks were spread out on tarps and spray painted (Figure 4) using an industrial airless sprayer. One side was sprayed, allowed to dry, turned over, and the opposite side sprayed. Paint used for tracer gravel consisted of a 2-part polyamide epoxy coating by

Benjamin Moore.

<u>Paint: (part one)</u>
Polyamide Epoxy Coating - Clear base M36 92
Additives: MY - 10Y - 28, UO - Y12 (orange)
TW 20, MY40, OY - 8Y8 (yellow)
<u>Catalyst: (part two)</u>
Polyamide Epoxy Coating - Semi-Gloss catalyst M38 - 84
Mixing ratio 1gal:1gal thinned to 10%, as necessary, with NEK or High Flash Naptha

Figure 4. Painting the tracer rocks placed in the three wing dams.

Tracer Gravel Installation

Tracer gravel was installed in three gravel wing diversion dams on the Merced River before the first high flow event of the 2000 - 2001 salmon spawning season. The three sets of gravel (two yellow and one orange) were installed in alternating colors moving downstream at each of the respective wing dams (wing dam no. 3: yellow; wing dam no. 4: orange; and wing dam no. 5: yellow). The tracer gravel was placed in portions of each wing dam most likely to be scoured by high flows. Gravel locations were plotted in relation to a transect line with semi-permanent endpins and with satellite GPS. Tracer gravel was placed approximately one foot deep to avoid human disturbance (Figure 5).

Figure 5. Placement of painted tracer rocks just below the surface of a wing dam.

Tracer Gravel Monitoring

After a high-flow event (originally planned for at least 3,000 cfs), a survey of the tracer-gravel's position was performed. Using the same endpins placed at each survey site at the time of installation, a transect line was stretched across the river marking the initial location of each placement group. From the transect line, near the initial placement points, a measuring tape was used to measure the distance of downstream movement.

The tracer-gravel surveys included visual observations of individual tracer rocks identifiable without moving or manipulating the gravel bed. To aid in tracer-gravel identification of rocks covered by water, a three-and-one-half-gallon bucket with the bottom cut out and replaced with Plexiglas was used for underwater observations. To ensure that all areas of the gravel bed suspected of containing tracer gravel was surveyed, the downstream-most extent of the wing dam gravel was determined and cross transects every ten feet, moving upstream, were established with two observers to locate tracer rocks. With the aid of the clear-bottom buckets in fast or deep water, each observer searched approximately five feet up and downstream while moving across the river.

After locating a tracer rock, the three-dimensional measurement was obtained using the same methods described earlier, along with the rock's distance downstream of the transect line (to the nearest foot in most cases) and the GPS coordinates. The crossing pattern through the survey area continued upstream until all of the gravel bed within the survey area was covered. If a group of tracer gravel did not wash out, its position was noted along with the number observed at surface level. Because each survey was performed during a low-flow period, gravel bars above water and downstream of the transect line were included in the survey.

Radio Telemetry Rock Preparation

Twenty rocks within the range suitable for spawning gravel were selected for radio transmitter[1] attachment. To accommodate installation of the radio transmitters into each rock, size of the selected rocks chosen were: X > 3.5-in, Y > 3-in, and Z > 2-in. The average size of the telemetry rocks was larger than the average size of the tracer rocks because of the size of the radio transmitters. Rocks were measured and pre-weighed. Each weight was noted on the rock. Utilizing a local gem dealer, a 3/4-in wide x 3-in deep hole was drilled into each rock to hold the transmitter with ¼-in added depth to allow for the antenna to bend and lay in a scrolled groove cut into the rock. Transmitters were cemented into the rocks using *Simpson Strongtie Connectors* epoxy and the antennas were cemented around each rock using *PC-11 Marine Power* epoxy paste. During transmitter installation, thin strips of lead were pushed in around the transmitter to adjust for original weight. Excess epoxy paste was sanded down to the original shape of the rock and, with the careful addition of lead, the final weight was adjusted to within 1.5% of the original weight. The radio frequency was written on the outside of each rock as well as etched into the rock using an electric engraver with a tungsten carbide tip.

Radio Telemetry Rock Installation

Telemetry rocks were separated within the river so that any overlapping frequencies were at different wing dam locations. Six or seven rocks were placed at each wing dam, along with the tracer gravel, in the area of the wing dam most likely to be scoured by high flows. Location of each telemetry rock (with corresponding frequency) relative to the transect line was recorded along with GPS coordinates.

Radio Telemetry Rock Monitoring

Radio telemetry monitoring was performed during the tracer-gravel surveys. A Telonics TR2 receiver with a small directional Yagi antenna was used to locate individual rocks. A simple triangulation method was used to locate the general location of each rock. Subsequently, a more precise location, to within five feet, was determined by wading to each signal origin until it was pinpointed. The telemetered-rock location was recorded relative to distance downstream of the transect line and with GPS coordinates.

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[1] Radio transmitters were Advanced Telemetry Systems, Inc. Model F1850, cylindrical shape, 17 mm diameter by 68 mm long, 25 grams.

RESULTS

Installation of tracer rocks occurred in each of the three wing dams on October 7, 2000 and installation of the telemetry rocks occurred on October 12, 2000. After tracer rocks and telemetry rocks were placed in each of the three wing dams, three increased flow events greater than 1,000 cfs occurred (Figure 6)[2]. The first increased flow event occurred in late October 2000. For the period from October 21 through October 26, 2000, mean daily river flows exceeded 1,000 cfs with a peak mean daily flow of 1,365 cfs on October 22, 2000 (Figure 6). Subsequent flows greater than 1,000 cfs occurred during the Vernalis Adaptive Management Program (VAMP) in the spring of 2001 and 2002. In April and May 2001, two pulse flows greater than 1,000 cfs occurred; from April 19 through April 26 and May 8 through May 16, 2001, respectively, with a peak mean daily flow of 1,345 cfs on May 11, 2001 (Figure 6). In May 2002, mean daily flows exceeded 1,000 cfs from May 1 through May 7 and on May 11 with a peak mean daily flow of 1,402 cfs on May 3, 2002 (Figure 6).

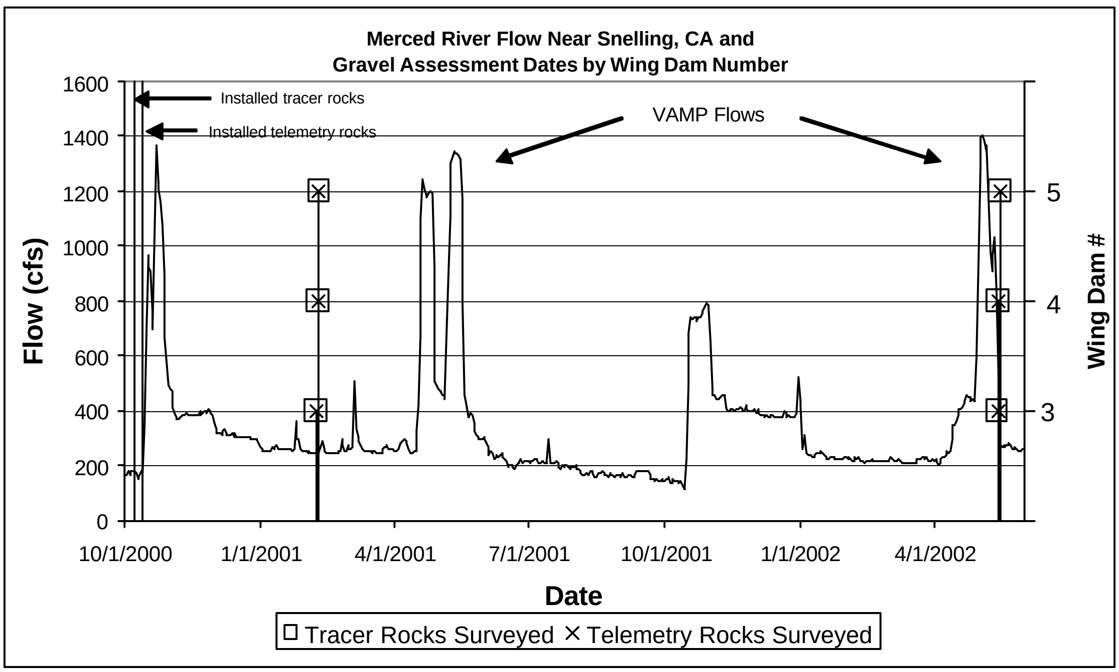

Figure 6. River flows (cfs) near Snelling, CA from October 1, 2000 through May 31, 2002 showing dates of installation of tracer and telemetry rocks and survey dates for each wing dam.

The original objective of the study was to observe changes in the distribution of the tracer and telemetry rocks after high flow events of at least 3,000 cfs. Flow events during the study period were substantially less than that level (<1,400 cfs) (Figure 6). The most useful data acquired during the study occurred after the initial flow event in October 2000. Flows during this period scoured each of the three gravel wing dams. At each study site, the sections of the wing dam where the telemetry and tracer rocks were placed

[2] Flow data obtained from California Department of Water Resources, California Data Exchange Center, Merced River stream gauging station near Snelling (Station ID MSN).

had been partially scoured and redistributed downstream.

After subsequent increased flow events, the gravel at each of the wing dams was moved back upstream by the water diverters using heavy equipment as part of their routine operations. This circumstance precluded meaningful data necessary for study purposes because tracer gravel and telemetry rocks were artificially moved back upstream. However, data are provided here for informational purposes.

The following provides results obtained at each of the three wing dams.

Wing Dam No. 3

A survey of gravel movement from wing dam no. 3 was conducted on February 7, 2001. The entire portion of the wing dam containing the tracer and telemetry rocks was scoured from the October 2000 flow event, washing that portion of the wing dam downstream up to 122 feet. All telemetry rocks were located and found to have moved an average distance downstream of 65 feet (range 33-81 feet) (Table 3). Of the 29 tracer rocks located among the original 2,619 tracer rocks placed in the wing dam (1.1% recovery), the average downstream movement was 88 feet (range 43-122 feet) (Table 3).

Table 3. Wing dam no. 3 downstream movement of telemetry and tracer rocks in feet.

	Telemetry	Tracer	
Min	33	43	
Max	81	122	
Mean	65	88	
Standard Deviation	18.1	22.3	
N	6 / 6	29 / 2619	1.1%

As part of the study, the average diameter of each tracer rock located was recorded along with its location downstream of the transect line. The dispersal of those rocks by size and distance are shown in Figure 7.

Data for the surveys performed at wing dam no. 3 on February 7, 2001 and May 13, 2002 are provided in Appendices A - D.

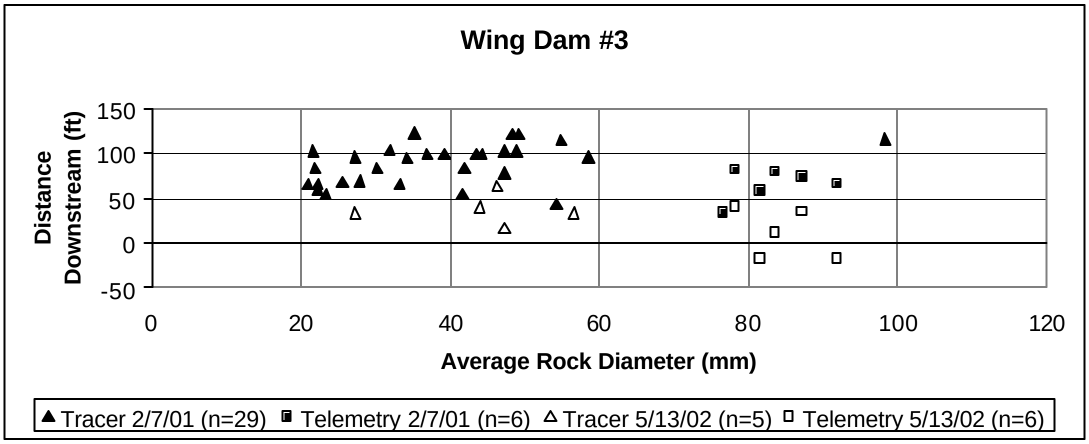

Figure 7. Tracer rock and telemetry rock displacement distances (feet) and average rock diameter determined from surveys at wing dam no. 3 on February 7, 2001 and May 13, 2002.

The overall dispersal of tracer and telemetry rocks in plan-view perspective is shown in Figure 8.

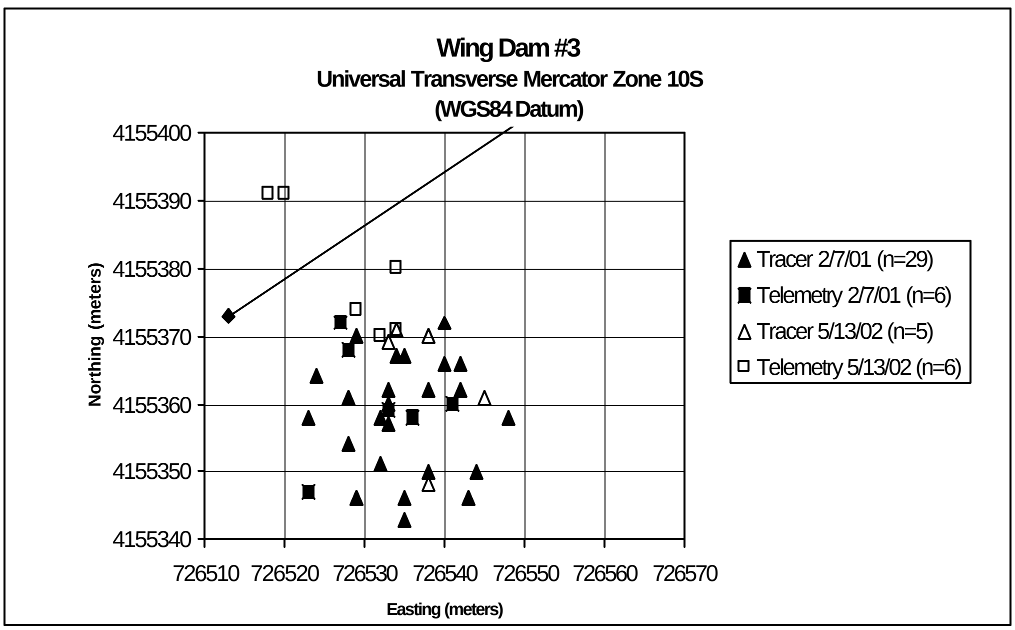

Figure 8. Dispersal of tracer and telemetry rocks shown in plan-view perspective at wing dam no. 3. River flow is from upper left to lower right. Diagonal line shows transect line along original wing dam location.

As noted during the May 13, 2002 survey, artificial upstream displacement from wing dam reconstruction is evident from the telemetry rocks (Figures 7 and 8).

Figures 9 and 10 show the condition of wing dam no. 3 on September 20, 2000 and February 20, 2003.

Figure 9. Pictures of wing dam no. 3 (looking downstream) taken on September 20, 2000 (top) and February 20, 2003 (bottom).

Figure 10. Pictures of wing dam no. 3 (looking toward the left, south east bank) taken on September 20, 2000 (top) and February 20, 2003 (bottom).

Wing Dam No. 4

A survey of gravel movement from wing dam no. 4 was conducted on February 8, 2001. Portions of this wing dam containing the telemetry and tracer rocks were scoured from the October 2000 flow event washing those rocks downstream up to 186 feet. This wing dam washed out in a fan pattern in which the gravel from the wing dam initially traveled downstream and then fanned right, distributing over a pre-existing, large riffle.

All telemetry rocks were located and found to have moved an average distance downstream of 87 feet (range 36-162 feet) (Table 4). Of the 39 tracer rocks located among the original 2,805 tracer rocks placed in the wing dam (1.4% recovery), the average downstream movement was 86 feet (range 57-186 feet) (Table 4).

Table 4. Wing dam no. 4 downstream movement of telemetry and tracer rocks in feet.

	Telemetry	Tracer	
Min	36	57	
Max	162	186	
Mean	87	86	
Standard Deviation	51.1	42.4	
N	7 / 7	39 / 2805	1.4%

The average diameter of each tracer rock located was recorded along with its location downstream of the transect line. The dispersal of those rocks by size and distance are shown in Figure 11.

Data for the surveys performed at wing dam no. 4 on February 8, 2001 and May 14, 2002 are provided in Appendices E - H.

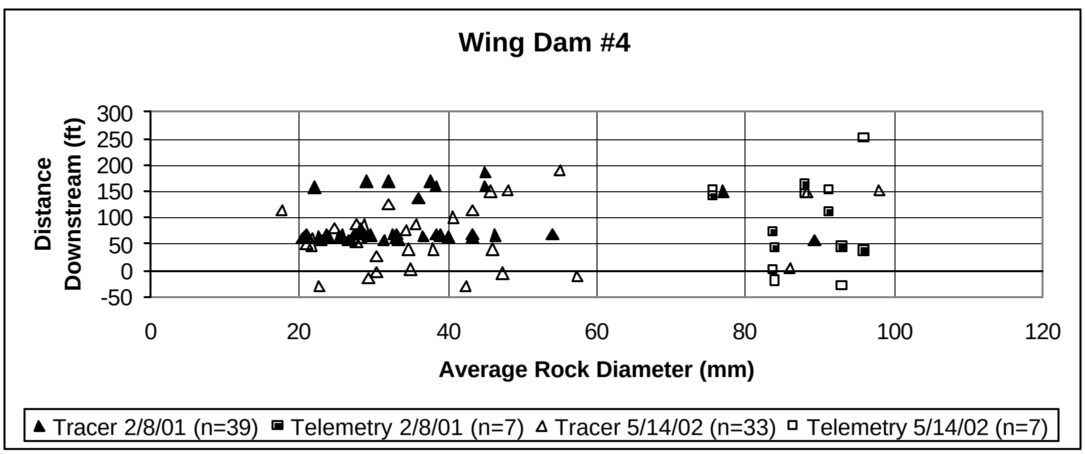

Figure 11. Tracer rock and telemetry rock displacement distances (feet) and average rock diameter determined from surveys at wing dam no. 4 on February 8, 2001 and May 14, 2002.

The overall dispersal of all tracer and telemetry rocks in plan-view perspective is shown in Figure 12.

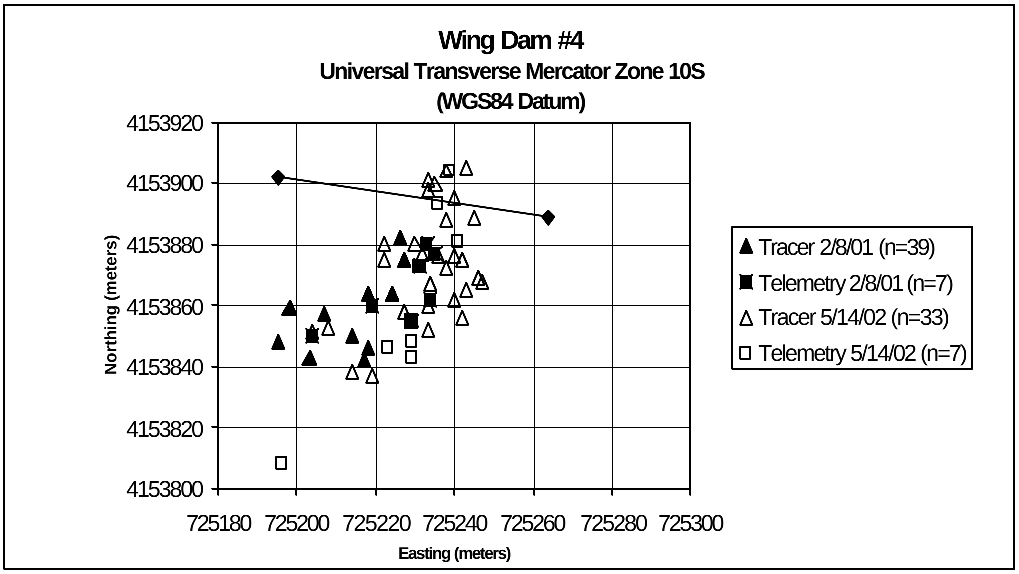

Figure 12. Dispersal of tracer and telemetry rocks shown in plan-view perspective at wing dam no. 4. River flow is from top to bottom. Diagonal line shows transect line along original wing dam location.

As noted during the May 14, 2002 survey, artificial upstream displacement from wing dam reconstruction is evident from both the telemetry and tracer rocks (Figures 11 and 12).

Figures 13 and 14 show the condition of wing dam no. 4 in December 2000 and February 2003.

Figure 13. Pictures of wing dam no. 4 (looking toward the left, southeast bank) taken on September 20, 2000 (top) and February 20, 2003 (bottom).

Figure 14. Pictures of wing dam no. 4 (looking downstream) taken on December 3, 2000 (top) and February 20, 2003 (bottom).

Wing Dam No. 5

A survey of gravel movement from wing dam no. 5 was conducted on February 9, 2001. The scoured portions of the wing dam were washed up to 130 feet. All telemetry rocks were located and found to have moved an average distance downstream of 50 feet (range 11-81 feet) (Table 5). Of the 317 tracer rocks located among the original 2,638 tracer rocks placed in the wing dam (12 % recovery), the average downstream movement was 34 feet (range 7-130 feet) (Table 5).

Table 5. Wing dam no. 5 downstream movement of telemetry and tracer rocks in feet.			
	Telemetry	Tracer	
Min	11	7	
Max	81	130	
Mean	50	34*	
Standard Deviation	28.2	33.4	
N	7 / 7	317 / 2638	12.0%

* 216 tracer rocks were found within 18 feet of their original location. Excluding those rocks yields an average movement of 76 ft.

The average diameter of each tracer rock located was recorded along with its location downstream of the transect line. The dispersal of those rocks by size and distance are shown in Figure 15.

Data for the surveys performed at wing dam no. 5 on February 9, 2001 and May 15, 2002 are provided in Appendices I - L.

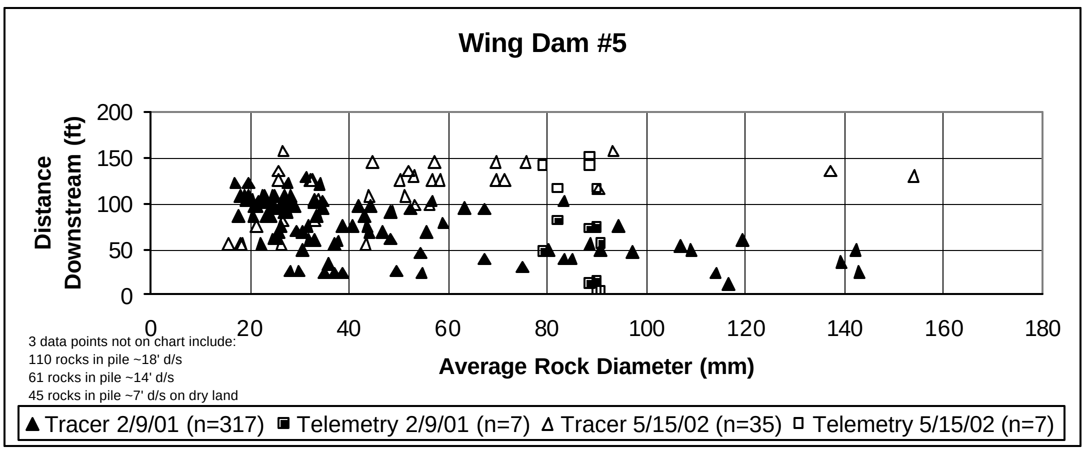

Figure 15. Tracer rock and telemetry rock displacement distances (feet) and average rock diameter determined from surveys at wing dam no. 5 on February 9, 2001 and May 15, 2002.

The overall dispersal of all tracer and telemetry rocks in plan-view perspective is shown in Figure 16.

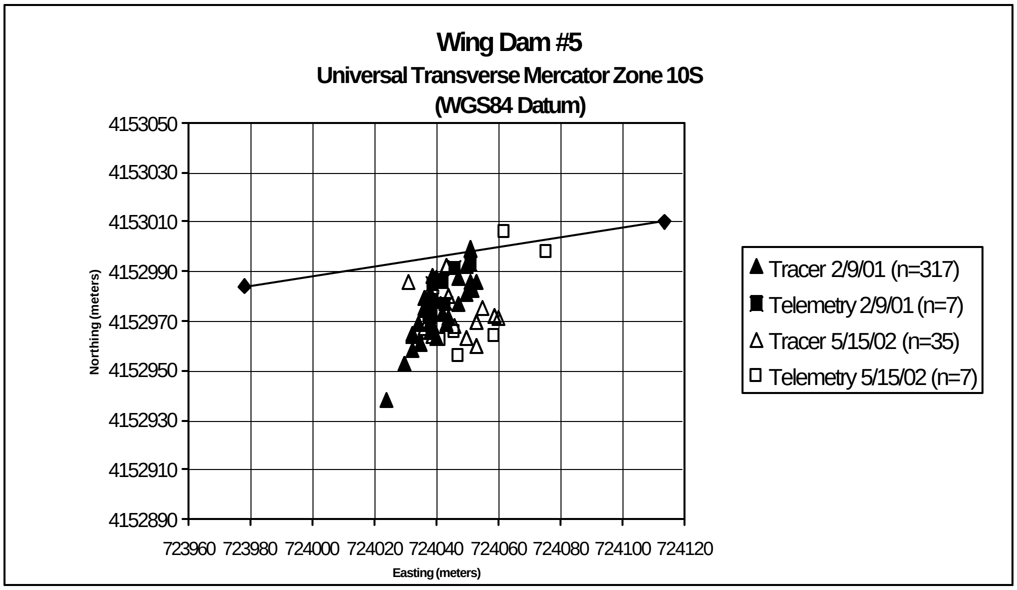

Figure 17. Dispersal of tracer and telemetry rocks shown in plan-view perspective at wing dam no. 5. River flow is from top to bottom. Diagonal line shows transect line along original wing dam location.

Figures 18 and 19 show the condition of wing dam no. 5 in 2000 and 2003.

Figure 18. Pictures of wing dam no. 5 (looking toward the left, southeast bank) taken on September 21, 2000 (top) and February 20, 2003 (bottom).

Figure 19. Pictures of wing dam no. 5 (looking toward the left, southeast bank) taken on December 3, 2000 (top) and February 20, 2003 (bottom).

DISCUSSION

During the study period, CDFG conducted the annual fall-run Chinook salmon spawning ground surveys and recorded the maximum number of redds at each of the wing dam sites. The data were collected for the entire riffle area in the vicinity of the wing dam and are provided in Table 6. It is evident that all three sites are used by salmon for spawning. There were no apparent trends in spawning abundance at each of the three wing dam riffles between years. The relative proportional distribution of salmon between the three sites was similar among these three years. However, spawning distribution in the vicinity of wing dam no. 5 was generally about one-half to one-third than that observed at the upstream wing dams no. 3 and 4, suggesting that the upstream sites may be more important areas or, at least, more heavily utilized.

Table 6. Maximum number of salmon redds observed in the vicinity of the three wing dams during 2000, 2001, and 2002 and corresponding salmon run sizes for those years.*

Wing Dam and CDFG Riffle No.	Maximum Number of Redds		
	2000	2001	2002
Dam 3 – Riffle E1	25	9	25
Dam 4 – Riffle F2	28	9	32
Dam 5 – Riffle G7	11	3	13
In-River Run Size	7,179	8,000	8,800

* Preliminary data provided by CDFG; redd counts provided by Ken Johnson (CDFG) and 2000 - 2002 in-river run sizes provided by Bob Kano, (CDFG) (Central Valley Grandtab data table).

Several circumstances limited achieving the overall study objectives. Flows greater than 3,000 cfs did not occur during the study period. Although the original intent of the study was to monitor the downstream dispersal of salmon spawning gravels at flows greater than 3,000 cfs, dispersal of rocks was significant even at flows slightly greater than 1,000 cfs. Downstream movement of tracer rocks and telemetry rocks occurred at all three wing dams within these salmon spawning areas as a result of the increased flows in October 2000. Site-specific physical and hydraulic conditions at each site causing the dispersal were beyond the scope of this study but provided empirical evidence that flows considerably less than 3,000 cfs achieve downstream movement of spawning gravels placed at these sites. However, reconstruction of the three wing dams using existing riverbed substrate in the spring following placement of tracer and telemetry rocks prevented acquisition of useful data after those events.

Despite these limitations, placement of clean spawning gravels in wing dams appears to have merit because of: 1) the need for replenishment of spawning gravels in the river; 2) addition of gravels at the sites minimizes the in-river channel disturbance that would otherwise occur for seasonal wing dam construction, and 3) significant downstream dispersal occurs at flows substantially less than 3,000 cfs. However, for this management measure to result in biological benefit, the wing dam gravel should have been supplemented after increased flows moved the gravel downstream. Without supplementation of spawning gravels at the sites, routine wing dam maintenance will result in regular mechanical re-distribution of the gravels back upstream to form the wing dams. Additionally, the spring-time flows in the Merced River for VAMP creates a situation where the wing dams are partially scoured causing the water diverters at the sites to move gravels back upstream twice instead of the usual one-time-per-season basis. Therefore, even if additional spawning gravels were added to the wing dam sites at the onset of the diversion season, subsequent VAMP flows would have mobilized wing dam gravels downstream and necessitated reconstruction of the dams after VAMP flows subsided. Avoidance of this latter circumstance would have required two spawning gravel supplementations each spring (pre- and post-VAMP).

The technique of using painted tracer rocks and telemetry rocks worked well to monitor downstream dispersal of rocks in wing dams on the Merced River. The telemetry rocks functioned well from the time of placement in the fall of 2000 through the spring of 2002. The paint on the tracer rocks proved to be particularly durable, lasting for more than two years after placement in the river (Figure 20).

Figure 20. Painted tracer rocks recovered from the Merced River after being in the river for more than two years.

Although the two techniques to monitor gravel movement were effective for purposes of the study, each technique had advantages and disadvantages. Tracer rocks were less expensive and were, therefore, prepared in greater quantities than telemetry rocks. The paint on tracer rocks proved to be sufficiently durable in the riverine environment demonstrating that the technique could be used for long-term studies. Additionally, tracer rocks could be prepared among a wider-size range than telemetry rocks and, therefore, provided a more-representative characterization of salmon spawning gravels. However, tracer rocks were only useful if the rocks could be visibly seen on the surface of the riverbed which significantly reduced the recovery efficiency after the rocks had been mobilized by increased flow events. Telemetry rocks were more expensive to prepare and were limited to larger-size ranges (compared to tracer rocks). As a result, those rocks were less representative of salmon spawning gravels. Smaller radio transmitters could be placed inside smaller rocks but the smaller battery would result in greatly diminished transmitter life reducing the technique's effectiveness to only very short-term studies (e.g., weeks or months as compared to years). However, the recovery (detection) efficiency of telemetry rocks was consistently 100 percent because radio transmitter signals could be detected and triangulated even when the telemetry rocks were buried under the river bed after increased flow events.

RECOMMENDATIONS

- Continue the practice of providing wing-dam operators with clean gravels for the construction of temporary diversion dams.

The provision of clean gravels at wing-dam sites is one way of replenishing Merced River salmon spawning gravels. Adding the spawning gravels at the diversion sites is advantageous because it minimizes the usual mechanical disturbance of the river bed and mobilization of fine sediments during low-flow periods. Although data from this study could not determine the sites most appropriate for gravel additions, it appears to be an appropriate management measure to continue until such time that more data on the topic are acquired.

Two circumstances diminished the effectiveness of the study but could be overcome during performance of future, similar studies:

- Conduct the study during periods when high flows can be reasonably anticipated.

Although study rocks moved during much lower flows than anticipated, a future study should be performed when anticipated higher winter flows would be expected. The probability of high winter flows in the study reach is increased during periods when the primary upstream storage reservoir (Lake McClure) is at relatively high levels in the fall prior to flood control operations. At higher carryover storage levels, there is an increased probability of higher winter-time reservoir releases as compared to low carryover storage levels. For example, in examining readily-available historical records for 24 water years, 50% percent of those years when October storage was less than 400,000 acre-feet, flows of 3,000 cfs or greater occurred during the same water year. In contrast, 86% of those years when October storage was greater than 600,000 acre-feet, flows of 3,000 cfs or greater occurred during the same water year. If an additional study is undertaken, it should be performed when Lake McClure is at high late-season levels to increase the probability of data collection during flows of greater than 3,000 cfs.

- Conduct the study when it can be expected that additional clean gravels will be provided to reconstruct the wing dams after a high-flow period.

The second circumstance that did not occur during this study, but could be accommodated in future studies, would be to provide the wing dam operators with additional clean gravels following the period when high flows mobilize the original wing dam substrate (and study rocks) downstream. This measure would reduce the probability of study rocks being artificially moved back upstream during subsequent wing dam construction. It would also provide a longer study period to determine dispersal of wing dam gravels. The study should be conducted only if funding was secured to purchase additional clean gravels or the wing dam material was stockpiled at the site in advance of the study.

ACKNOWLEDGMENTS

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Appendix A. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #3 on February 7, 2001.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	D	Easting (m)	Northing (m)
1	65	9	25	29	21.0	726548	4155358
2	100	19	41	73	44.3	726532	4155358
3	102	15	19	31	21.7	726532	4155351
4	100	28	42	48	39.3	726538	4155348
5	100	27	40	64	43.7	726535	4155343
6	96	30	72	74	58.7	726523	4155358
7	94	26	28	49	34.3	726542	4155366
8	96	11	30	41	27.3	726538	4155350
9	100	23	30	58	37.0	726533	4155362
10	103	23	35	38	32.0	726542	4155362
11	83	16	20	30	22.0	726528	4155354
12	83	11	34	46	30.3	726528	4155361
13	83	20	51	55	42.0	726528	4155361
14	77	30	42	70	47.3	726533	4155360
15	65	14	25	28	22.3	726534	4155367
16	66	26	34	40	33.3	726529	4155370
17	69	16	28	40	28.0	726533	4155357
18	68	11	31	35	25.7	726535	4155367
19	60	14	24	29	22.3	726540	4155366
20	54	35	39	51	41.7	726538	4155362
21	54	16	22	32	23.3	726540	4155372
22	43	26	58	79	54.3	726524	4155364
23	116	61	115	119	98.3	726535	4155346
24	102	24	49	69	47.3	726529	4155346
25	102	22	44	81	49.0	726529	4155346
26	114	30	46	89	55.0	726529	4155346
27	121	22	50	73	48.3	726543	4155346
28	121	24	61	63	49.3	726543	4155346
29	122	23	30	53	35.3	726544	4155350

Appendix B. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #3 on February 7, 2001.

Frequency	UTM Zone 10S (WGS84)		Est. Feet d/s
	Easting (m)	Northing (m)	Tag Line
159.246	726536	4155358	66
159.274	726527	4155372	33
159.345	726523	4155347	80
159.365	726533	4155359	73
159.384	726528	4155368	57
159.418	726541	4155360	81

Appendix C. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #3 on May 13, 2002.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	d	Easting (m)	Northing (m)
1	40	26	35	71	44.0	726534	4155371
2	16	27	36	79	47.3	726533	4155369
3	63	41	46	52	46.3	726545	4155361
4	33	12	34	36	27.3	726538	4155370
5	33	27	63	80	56.7	726538	4155370

Appendix D. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #3 on May 13, 2002.

Frequency	UTM Zone 10S (WGS84)		Est. Feet d/s Tag Line
	Easting (m)	Northing (m)	
159.246	726518	4155391	-18
159.274	726529	4155374	34
159.345	726534	4155380	11
159.365	726532	4155370	35
159.384	726520	4155391	-18
159.418	726534	4155371	40

Appendix E. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #4 on February 8, 2001.

	Est. Feet d/s Tag Line	Geometric Measurement				UTM Zone 10S (WGS84)	
		x	y	z	d	Easting (m)	Northing (m)
1	186	35	42	58	45.0	725217	4153842
2	160	22	43	70	45.0	725218	4153846
3	150	60	66	105	77.0	725214	4153850
4	168	18	34	35	29.0	725198	4153859
5	168	28	40	45	37.7	725198	4153859
6	168	22	24	50	32.0	725198	4153859
7	159	20	37	58	38.3	725203	4153843
8	158	16	22	28	22.0	725195	4153848
9	136	18	42	48	36.0	725207	4153857
10	68	18	29	51	32.7	725224	4153864
11	68	38	43	81	54.0	725224	4153864
12	68	11	31	57	33.0	725224	4153864
13	68	19	24	43	28.7	725224	4153864
14	68	17	17	29	21.0	725224	4153864
15	68	21	27	34	27.3	725224	4153864
16	68	26	44	60	43.3	725224	4153864
17	68	16	44	55	38.3	725224	4153864
18	66	28	38	51	39.0	725224	4153864
19	66	27	51	61	46.3	725224	4153864
20	66	22	23	44	29.7	725224	4153864
21	66	16	20	41	25.7	725224	4153864
22	66	11	22	38	23.7	725224	4153864
23	64	9	34	45	29.3	725227	4153875
24	64	21	38	51	36.7	725227	4153875
25	63	19	19	24	20.7	725227	4153875
26	63	8	25	35	22.7	725227	4153875
27	63	31	34	65	43.3	725227	4153875
28	63	19	36	44	33.0	725227	4153875
29	63	18	24	34	25.3	725227	4153875
30	63	12	18	42	24.0	725227	4153875
31	62	19	26	32	25.7	725218	4153864
32	62	26	40	54	40.0	725218	4153864
33	58	26	30	44	33.3	725218	4153864
34	57	22	26	46	31.3	725218	4153864
35	57	9	41	44	31.3	725218	4153864
36	58	21	28	32	27.0	725218	4153864
37	58	15	26	39	26.7	725226	4153882
38	57	73	73	122	89.3	725226	4153882
39	58	18	23	28	23.0	725226	4153882

Appendix F. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #4 on February 8, 2001.

Frequency	UTM Zone 10S (WGS84)		Est. Feet d/s Tag Line
	Easting (m)	Northing (m)	
159.302	725233	4153880	34
159.320	725204	4153850	142
159.331	725229	4153855	160
159.404	725235	4153877	44
159.443	725231	4153873	44
159.462	725234	4153862	79
159.471	725219	4153860	111

Appendix G. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #4 on May 14, 2002.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	d	Easting (m)	Northing (m)
1	4	52	95	111	86.0	725238	4153888
2	-30	33	44	50	42.3	725243	4153905
3	3	24	35	46	35.0	725245	4153889
4	-15	16	28	44	29.3	725233	4153898
5	40	36	25	77	46.0	725230	4153880
6	26	17	33	41	30.3	725222	4153875
7	86	22	22	42	28.7	725232	4153877
8	77	23	33	47	34.3	725242	4153856
9	61	12	23	30	21.7	725236	4153876
10	87	21	38	48	35.7	725234	4153867
11	87	16	29	38	27.7	725234	4153867
12	80	19	21	34	24.7	725246	4153869
13	80	14	33	38	28.3	725246	4153869
14	100	24	38	60	40.7	725240	4153862
15	53	23	25	35	27.7	725238	4153872
16	115	21	41	68	43.3	725227	4153858
17	115	10	20	23	17.7	725227	4153858
18	150	35	40	62	45.7	725204	4153851
19	60	11	15	35	20.3	725247	4153868
20	60	20	31	34	28.3	725243	4153865
21	48	11	24	30	21.7	725240	4153876
22	-5	38	42	62	47.3	725240	4153895
23	-4	22	25	44	30.3	725235	4153900
24	-10	20	56	96	57.3	725233	4153901
25	-30	14	22	32	22.7	725238	4153904
26	50	13	25	25	21.0	725222	4153880
27	40	23	32	49	34.7	725242	4153875
28	40	14	28	72	38.0	725242	4153875
29	125	24	33	39	32.0	725233	4153860
30	153	71	90	133	98.0	725214	4153838
31	190	45	49	71	55.0	725208	4153853
32	148	68	78	119	88.3	725233	4153852
33	153	21	48	75	48.0	725219	4153837

Appendix H. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #4 on May 14, 2002.

Frequency	UTM Zone 10S (WGS84) Easting (m)	UTM Zone 10S (WGS84) Northing (m)	Est. Feet d/s Tag Line
159.302	725196	4153808	250
159.320	725223	4153846	150
159.331	725229	4153848	145
159.404	725236	4153893	-30
159.443	725239	4153904	-20
159.462	725241	4153881	0
159.471	725229	4153843	152

Appendix I. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #5 on February 9, 2001.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	d	Easting (m)	Northing (m)
1	102	38	100	112	83.3	724034	4152969
2	102	15	27	27	23.0	724034	4152969
3	102	15	23	27	21.7	724034	4152969
4	102	29	32	43	34.7	724034	4152969
5	102	40	58	72	56.7	724034	4152969
6	102	10	23	36	23.0	724034	4152969
7	102	12	20	25	19.0	724034	4152969
8	100	15	22	30	22.3	724032	4152964
9	100	20	24	38	27.3	724032	4152964
10	100	18	19	33	23.3	724032	4152964
11	100	18	25	38	27.0	724032	4152964
12	100	20	23	43	28.7	724032	4152964
13	97	19	26	42	29.0	724038	4152969
14	97	18	27	33	26.0	724038	4152969
15	97	13	23	28	21.3	724038	4152969
16	97	12	28	33	24.3	724038	4152969
17	97	14	19	30	21.0	724038	4152969
18	103	20	35	44	33.0	724032	4152965
19	103	10	26	33	23.0	724032	4152965
20	103	18	19	36	24.3	724032	4152965
21	103	17	19	25	20.3	724032	4152965
22	108	20	22	33	25.0	724030	4152953
23	108	14	23	37	24.7	724030	4152953
24	108	14	16	27	19.0	724030	4152953
25	108	15	30	40	28.3	724030	4152953
26	108	13	20	21	18.0	724030	4152953
27	108	12	22	25	19.7	724030	4152953
28	108	13	19	37	23.0	724030	4152953
29	108	23	28	30	27.0	724030	4152953
30	122	17	24	42	27.7	724030	4152953
31	122	12	18	21	17.0	724030	4152953
32	122	16	18	25	19.7	724030	4152953
33	121	27	27	48	34.0	724032	4152958
34	129	23	25	46	31.3	724024	4152938
35	97	29	42	62	44.3	724035	4152961
36	97	25	38	63	42.0	724035	4152961
37	95	17	33	54	34.7	724035	4152961
38	95	21	24	30	25.0	724035	4152961
39	95	59	62	69	63.3	724035	4152961

Appendix I. Merced River Wing Dam Gravel Monitoring
(continued) Tracer Rock Recovery of Wing Dam #5 on February 9, 2001.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	d	Easting (m)	Northing (m)
40	94	34	53	70	52.3	724035	4152961
41	90	40	48	57	48.3	724043	4152969
42	90	31	46	69	48.7	724043	4152969
43	93	39	55	108	67.3	724042	4152973
44	93	22	23	36	27.0	724042	4152973
45	90	16	30	35	27.0	724038	4152981
46	90	10	29	44	27.7	724038	4152981
47	86	14	32	55	33.7	724039	4152968
48	86	13	27	32	24.0	724039	4152968
49	86	14	18	30	20.7	724039	4152968
50	86	16	23	31	23.3	724039	4152968
51	86	18	28	54	33.3	724039	4152968
52	86	32	35	62	43.0	724039	4152968
53	86	11	14	28	17.7	724040	4152963
54	78	43	66	68	59.0	724040	4152963
55	75	36	97	150	94.3	724040	4152963
56	75	11	33	35	26.3	724040	4152963
57	75	31	40	60	43.7	724040	4152963
58	75	13	30	52	31.7	724040	4152963
59	75	27	47	48	40.7	724038	4152970
60	75	22	39	55	38.7	724038	4152970
61	69	20	50	62	44.0	724036	4152974
62	70	17	28	43	29.3	724036	4152974
63	69	15	34	43	30.7	724038	4152966
64	69	31	31	78	46.7	724038	4152966
65	69	29	62	76	55.7	724038	4152966
66	69	18	26	33	25.7	724038	4152966
67	60	23	29	44	32.0	724044	4152971
68	60	20	35	44	33.0	724044	4152971
69	60	62	143	153	119.3	724044	4152971
70	58	17	43	53	37.7	724044	4152971
71	61	17	43	85	48.3	724036	4152979
72	61	17	25	32	24.7	724036	4152979
73	61	14	25	37	25.3	724036	4152979
74	55	10	26	31	22.3	724038	4152972
75	55	15	43	53	37.0	724047	4152987
76	55	43	63	160	88.7	724047	4152987
77	49	52	65	124	80.3	724036	4152975
78	49	12	33	47	30.7	724036	4152975

Appendix I. Merced River Wing Dam Gravel Monitoring
(continued) Tracer Rock Recovery of Wing Dam #5 on February 9, 2001.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	y	z	d	Easting (m)	Northing (m)
79	49	126	136	165	142.3	724036	4152975
80	45	27	48	88	54.3	724036	4152975
81	53	77	102	142	107.0	724050	4152981
82	49	45	97	130	90.7	724052	4152983
83	49	98	112	117	109.0	724052	4152983
84	47	75	84	133	97.3	724051	4152986
85	39	44	100	111	85.0	724047	4152987
86	39	40	69	93	67.3	724047	4152987
87	39	50	83	117	83.3	724047	4152987
88	31	37	69	119	75.0	724039	4152988
89	34	17	42	48	35.7	724039	4152988
90	11	74	116	160	116.7	724047	4152977
91	36	105	143	170	139.3	724053	4152986
92	34	33	37	38	36.0	724053	4152986
93	26	22	28	34	28.0	724050	4152992
94	26	25	31	34	30.0	724050	4152992
95	26	29	47	73	49.7	724050	4152992
96	25	99	128	202	143.0	724050	4152992
97	24	25	56	83	54.7	724050	4152992
98	24	25	37	54	38.7	724050	4152992
99	24	20	43	42	35.0	724050	4152992
100	24	67	122	153	114.0	724050	4152992
101	23	31	33	47	37.0	724050	4152992
*	18	--	--	--	--	724051	4152999
**	14	--	--	--	--	724051	4152999
***	<7	--	--	--	--	---	---
* 110 rocks on surface in pile							
** 61 rocks on surface in pile							
*** 45 rocks on dry land							

Appendix L. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #5 on May 15, 2002.

Frequency	UTM Zone 10S (WGS84) Easting (m)	UTM Zone 10S (WGS84) Northing (m)	Est. Feet d/s Tag Line
159.257	724047	4152956	150
159.284	724046	4152966	115
159.357	724059	4152964	115
159.376	724076	4152998	4
159.396	724034	4152961	140
159.425	724062	4153006	4
159.453	724041	4152962	140

Appendix K. Merced River Wing Dam Gravel Monitoring
Tracer Rock Recovery of Wing Dam #5 on May 15, 2002.

	Est. Feet d/s	Geometric Measurement				UTM Zone 10S (WGS84)	
	Tag Line	x	Y	z	d	Easting (m)	Northing (m)
1	55	12	27	40	26.3	724043	4152992
2	55	35	42	53	43.3	724043	4152992
3	55	15	19	21	18.3	724043	4152992
4	81	21	34	44	33.0	724044	4152980
5	81	14	24	42	26.7	724044	4152980
6	108	26	30	76	44.0	724036	4152975
7	108	26	61	67	51.3	724036	4152975
8	108	11	23	34	22.7	724036	4152975
9	125	20	60	71	50.3	724040	4152987
10	125	40	51	84	58.3	724040	4152987
11	125	16	34	47	32.3	724040	4152987
12	125	20	27	30	25.7	724040	4152987
13	125	39	61	70	56.7	724040	4152987
14	135	32	54	70	52.0	724038	4152970
15	135	21	28	28	25.7	724038	4152970
16	135	117	130	165	137.3	724038	4152970
17	145	19	38	77	44.7	724060	4152971
18	100	24	33	42	33.0	724036	4152967
19	157	45	105	130	93.3	724039	4152964
20	157	16	22	42	26.7	724039	4152964
21	145	45	82	100	75.7	724050	4152963
22	145	30	52	90	57.3	724050	4152963
23	145	39	70	100	69.7	724053	4152970
24	125	14	31	53	32.7	724053	4152970
25	125	32	47	130	69.7	724053	4152970
26	125	39	81	94	71.3	724053	4152970
27	130	21	50	88	53.0	724053	4152960
28	130	92	150	220	154.0	724053	4152960
29	115	53	88	130	90.3	724055	4152975
30	105	17	33	51	33.7	724046	4152968
31	98	37	58	65	53.3	724059	4152972
32	98	45	54	70	56.3	724059	4152972
33	75	16	23	25	21.3	724031	4152986
34	55	12	11	24	15.7	724038	4152980
35	55	12	18	24	18.0	724038	4152980

Appendix L. Merced River Wing Dam Gravel Monitoring Telemetry Rock Recovery of Wing Dam #5 on February 9, 2001.

Frequency	UTM Zone 10S (WGS84)		Est. Feet d/s Tag Line
	Easting (m)	Northing (m)	
159.257	724039	4152978	57
159.284	724038	4152973	71
159.357	724046	4152991	14
159.376	724042	4152986	71
159.396	724043	4152977	77
159.425	724051	4152993	11
159.453	724039	4152985	39